

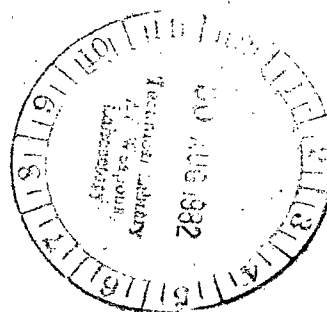
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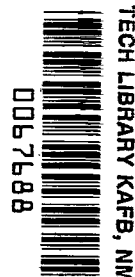
Venturi Nozzle Effects on Fuel Drop Size and Nitrogen Oxide Emissions

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Venturi Nozzle Effects on Fuel Drop Size and Nitrogen Oxide Emissions

Susan M. Johnson

*Lewis Research Center
Cleveland, Ohio*

NASA
National Aeronautics
and Space Administration

Scientific and Technical
Information Branch

SUMMARY

Experiments were conducted to determine the effect of a venturi nozzle on the performance of a simplex pressure-atomizing injector in a swirling airflow. In addition, the water spray droplet Sauter mean diameter D_{32} was measured with and without the venturi and correlated with oxides of nitrogen (NO_x) data obtained from a previous investigation using a similar combustor test configuration. The water pressure differential across the injector was varied from 0.386 to 1.158 megapascals, and the total air pressure drop across the swirler was 3 percent. The water spray was studied at ambient temperature (293 K) and atmospheric pressure. Using a venturi nozzle increased the relative air velocity and reduced D_{32} ; thus, in a combustor, the NO_x emission index (NO_xEI) would also be reduced. The ratio $\text{NO}_x\text{EI}/(D_{32})^2$ varied directly with equivalence ratio ϕ and constituted a single correlation of data obtained with and without the venturi.

INTRODUCTION

Emissions of gas turbine engine combustors have been the subject of many studies and programs (e.g., refs. 1 and 2). The study of reference 3 addressed the question of emissions and the adverse effect high oxides of nitrogen (NO_x) concentrations may have on the environment and the need for a continued effort to reduce NO_x emissions. One recent effort was conducted and reported in reference 4. In that experiment, NO_x concentrations were measured from three different types of fuel injectors inserted in an air swirler: simplex pressure-atomizing, splash-grooved, and splash-plate injectors. Also, NO_x measurements were taken when a venturi nozzle was installed with the injectors. The NO_x emissions were significantly reduced when a venturi nozzle was used. Since atomization data were lacking, it was impossible to tell whether the improvement was due to finer atomization or more rapid mixing of the fuel spray and the swirling airflow.

Other experiments at the NASA Lewis Research Center have utilized a scanning radiometer to measure droplet size of water jets (refs. 5 and 6). In the work of reference 7, a radiometer was used to measure mean drop size of five different types of swirl blast fuel injectors which had previously been used to obtain NO_x emission data. The mean drop diameter of the droplets was then related to the NO_x emission index (NO_xEI) by the empirical relation $\text{NO}_x\text{EI} \propto D_m^2$ (where D_m is mean drop size) at constant inlet air pressure and equivalence ratio. In addition to this empirical relation, the ratio $\text{NO}_x\text{EI}/D_m^2$ was used to show how primary-zone mixing might explain NO_xEI differences obtained with different fuel injectors.

Thus the present investigation was undertaken with a similar approach to relate NO_xEI to Sauter mean diameter (D_{32}) with and without a venturi nozzle at constant equivalence ratio ϕ . The experimental data and fuel injector configuration employed in reference 4 were used in the present study. In order to better understand the data reported in reference 4, water spray D_{32} values for the simplex injector were measured with and without the venturi, since this type of configuration gave the lowest NO_x emissions of the six configurations tested. The same air swirler and venturi were used. Combustor test conditions were simulated to measure equipollent spray droplet D_{32} values. These spray droplet D_{32} data were then correlated with the equivalent NO_x emission index from reference 4. The ratio $\text{NO}_x\text{EI}/(D_{32})^2$ was then calculated to ascertain whether the venturi affected spray atomization and/or mixing.

Correlated data of this nature are needed to predict how the atomization characteristics of a fuel injector are affected by peripheral hardware such as a venturi nozzle. Also, the technique of predicting D_{32} and NO_xEI values by using water instead of fuel reduces time and cost of combustor testing. Water is readily available and has the advantage of being nonflammable. Even though water has a surface tension three times greater than Jet A, surface tension effects pose no problem since they are well understood and can be accounted for in predicting D_{32} .

The experiment was conducted in an open-duct facility. The Sauter mean diameter of a water spray was determined at ambient temperature (293 K) and atmospheric pressure. The water pressure differential across the injector was varied from 0.386 to 1.158 megapascals, and the total air pressure drop across the swirler was 3 percent.

APPARATUS AND PROCEDURE

Test Facility

A schematic of the test facility is shown in figure 1. The injector-swirler pair was mounted on a 0.953-centimeter-thick plate and installed on a 15.24-centimeter-diameter pipe. Air was supplied by the Center's air system with a maximum test flow rate of 0.227 kilogram per second and a maximum test pressure of 7.79×10^3 pascals at the injector-swirler location. A static-pressure tap was located about 22.5 centimeters upstream of the injector and connected to a manometer board which was used to set the pressure differential across the swirler.

Water from the city water system was supplied to the injector. The water line to the injector was installed inside the air line with the U-bend in excess of 25 diameters upstream of the swirler to minimize any wake effects.

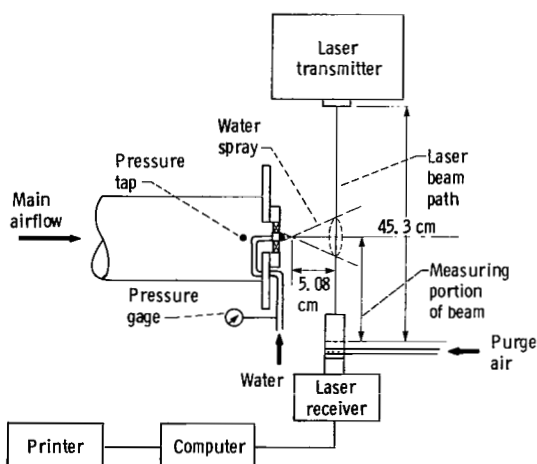


Figure 1. - Test facility schematic. (Not to scale.)

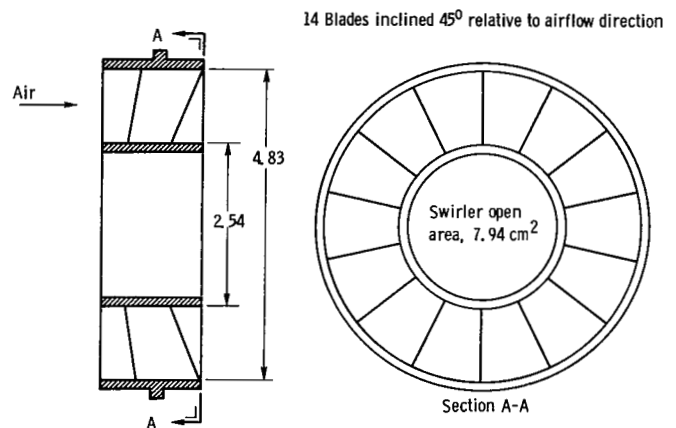


Figure 2. - Air swirler. (Dimensions in centimeters.)

Fuel Injector, Swirler, and Venturi

The simplex pressure-atomizing injector used was a Delavan model WDA-4.0, hollow cone, with a 45° spray angle. A Delavan model WDA-18.0 injector was used in reference 4 and initially in this experiment. This pressure-atomizing injector also emitted a hollow cone, with a 45° spray angle. The WDA 18.0 injector was eliminated for the reasons given in the RESULTS AND DISCUSSION.

The swirler is shown in figure 2. The 14 blades are inclined 45° relative to the airflow direction. The injector and the swirler were considered as a pair and remained installed on the plate throughout the experiment. Reference 4 reports the value of the swirler $C_d A$ as 5.94 square centimeters (where C_d is the discharge coefficient and A is the open swirler flow area).

The mixing venturi throat area was 175 percent of the swirler flow area, and the length from the swirler face to the throat was 28 percent of the venturi throat diameter, as shown in figures 3 and 4. The interior surfaces of the venturi were machined to achieve a smooth flow of air. Figure 4 shows the injector and the placement of the venturi with respect to the air swirler.

Drop Size Measurement

The measurement of D_{32} was achieved with a Malvern S.T. 1800 Particle and Droplet Size Distribution Analyzer. Figure 5 shows the various components of the Malvern instrument. The Malvern instrument is a nonintrusive optical system based on the Fraunhofer diffraction of a parallel monochromatic light beam scattered by moving droplets. The transmitter portion of the Malvern instrument houses the 2-milliwatt helium-neon laser and beam expander, which emits an approximately 9-millimeter-diameter beam. The receiver consists of a focusing lens (Fourier transform lens), a multielement photoelectric detector, beam alignment knobs, lamps, and an indicator. A computer with an 8-K memory receives, stores, and processes data inputs from the detector. A teletype with a hard copy printer is used for data output.

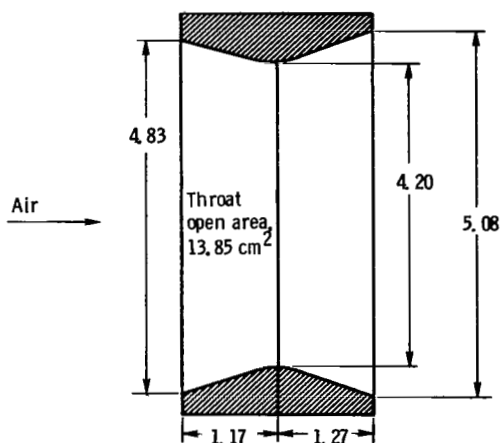


Figure 3. - Venturi nozzle. (Dimensions in centimeters.)

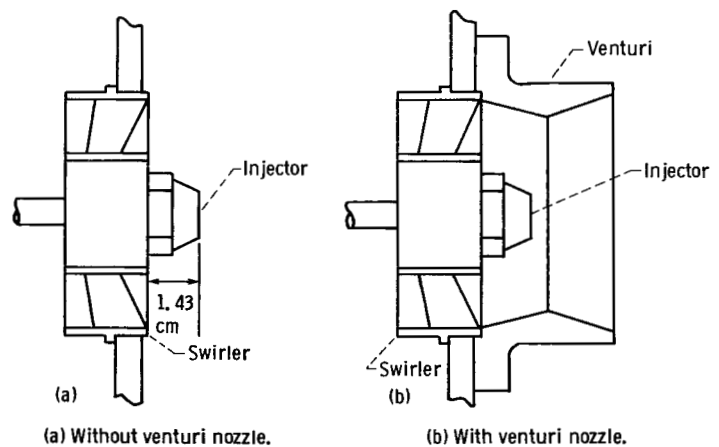


Figure 4. - Simplex pressure-atomizing injector test configurations.

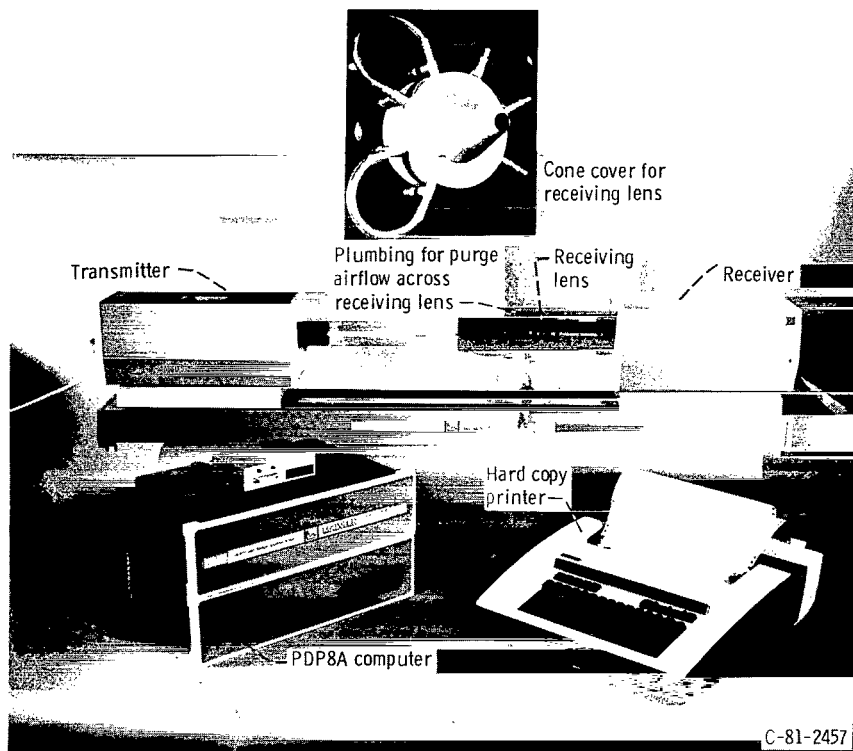


Figure 5. - Particle and droplet size distribution analyzer.

When a spray crossed the beam, the diffracted light ring patterns of the droplets were imaged onto the detector plate. The optical signal on the detector plate was converted to an electrical signal and fed into the computer memory. The computer compared the measured energy distribution with the Rosin-Rammler calculated energy distribution and printed the output on the hard copy printer. (The Rosin-Rammler distribution is described in ref. 8.) The output included the peak and width (spread) of the drop size distribution, an error value which describes the closeness of the fit between the calculated Rosin-Rammler and actually measured droplet distributions, and three different breakdowns of the spray distributions by percentage. These three distributions were cumulative percent by weight, normalized percent by number, and percent by weight fraction. The output is discussed in the appendix. A more complete description of the mathematics and details of the Malvern instrument optics are given in references 9 and 10.

Initially a black cylinder was positioned over the receiving lens of the laser (fig. 5) and was used to prevent droplet deposit on the lens. Air flowed through a copper tube and into the cylinder through eight equally spaced holes on the circumference to maintain positive pressure inside the cylinder and prevent droplet deposition on the lens. Later an aluminum cone was substituted for the cylinder and used for the majority of the experiment. (See inset in fig. 5.) The cone was an improvement over the cylinder for two reasons. First, the cone allowed only enough area for the beam to pass through, while minimizing the entry of stray droplets. Second, purge air was easily regulated at the vertex orifice so the spray pattern was not distorted while droplets were prevented from entering the cone and depositing on the receiving lens.

Test Procedure

Once the injector-swirler pair was installed, the laser beam of the Malvern instrument was positioned so that the spray was bisected and located in the measuring portion of the beam (see fig. 1). A hand-held light meter was used to measure and record laser beam intensity. Light intensity was checked before the first test of the day to ensure constant test beam intensity for this experiment. Before and occasionally during the experiment, background and laser alignment readings were checked. The alignment reading assured that the beam and the detector plate remained aligned during the experiment. The background reading measured any ambient light that fell onto the detector plate and was subtracted from the data energy signal when the distribution data were analyzed. The computer was programmed to scan the detector plate 1000 times and average the results. The time involved to record 1000 scans of one test condition was about 7 seconds. Once these preliminary steps were completed, purge air was passed across the receiving lens to prevent any minute droplets from accumulating on the lens and distorting the signal. A final background reading was taken with the purge air remaining on for the duration of the test.

The beam was positioned 5 centimeters downstream of the injector orifice. The desired air pressure differential across the swirler and the water flow rate to the injector were set. Water pressure data were always taken in order of increasing pressures. Two data points were taken for each water pressure setting and stored in the computer memory. The venturi was then installed, and the air and water flow conditions were repeated.

Test Simulation

Since this report compares experimental data from a combustor with those from cold-flow water experiments, a criterion combining these two sets of data is imperative. The approach taken in reference 7 to simulate combustor test conditions was to use the same airstream momentum, density times velocity, in both ambient cold-flow and combustor tests. However, the airstream momentum used in the reference 4 combustor studies was approximately four times greater than that available for this study. Also the surface tension of water is approximately three times greater than that of the fuel. The same type of injector with the same spray angle was used for both tests. The approach for this test was to equate liquid-air ratios between the two injectors. Differences in liquid and injector properties are taken into account by using equations presented in the next section. Injector selection is also discussed in the next section.

RESULTS AND DISCUSSION

The NO_x/EI data reported in reference 4 were obtained with a 45° spray-angle Delavan WDA-18.0 simplex fuel injector. To simulate fuel atomization in the combustor, the initial approach was to use the fuel injector WDA-18.0 from the study of reference 4 and test by injecting water into cold-flow (293 K) airstreams. At low water flow rates and pressure differentials, atomization was poor. Visual observation indicated that the spray angle was not fully developed until the water pressure differential

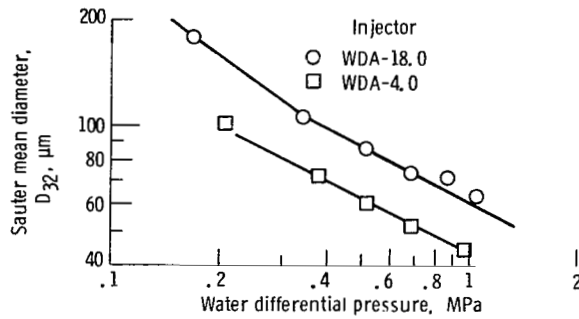


Figure 6. - Comparison of Sauter mean diameter of water sprays from injectors WDA-18.0 and WDA-4.0 in still air.

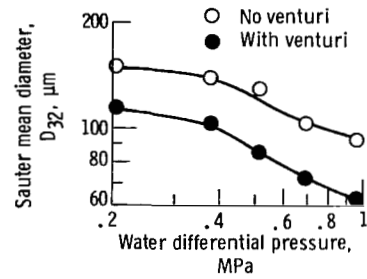


Figure 7. - Comparison of water droplet Sauter mean diameter for injector WDA-4.0 with and without venturi at swirler air-flow pressure drop of 3 percent.

TABLE I. - COMPARISON OF WATER SPRAY AND COMBUSTION TEST CONDITIONS

[Injector spray angle, 45°.]

Pressure differential, ΔP , MPa	Injector WDA-4.0; water spray test ^a			Injector WDA-18.0; combustion test ^b			
	Water mass flow rate, g/sec	Water-air ratio	Water velocity, m/sec	Fuel mass flow rate, g/sec	Fuel-air ratio	Fuel velocity, m/sec	Equivalence ratio, ϕ
0.386	2.40	0.045	7.59	9.66	0.036	8.53	0.528
.579	2.95	.056	9.30	11.84	.044	10.61	.646
.772	3.40	.064	10.76	13.70	.051	12.25	.749
.965	3.77	.071	11.89	15.24	.057	13.66	.837
1.158	4.13	.078	13.05	16.74	.062	14.94	.910

^aSwirler air mass flow rate, 52.8 g/sec.

^bSwirler air mass flow rate, 271.0 g/sec.

was past 0.345 megapascal. Thus injector WDA-18.0 appeared to be incorrectly sized for the cold-flow experiment.

Injector WDA-4.0 was then selected to determine its effect of pressure differential on D_{32} , as shown in figure 6. It can be observed in figure 6 that both fuel injectors at the higher water differential pressures conformed to the general relation

$$D_{32} \propto (\Delta P)^{-0.5} \quad (1)$$

where -0.5 represents the slope of a given injector. (Refs. 11 and 12 report variations of the exponent between -0.275 and -0.675 , but -0.5 is an acceptable and accurate exponent for these injectors.) A -0.5 exponent could not represent the case when fuel injector WDA-18.0 was operated at relatively low values of water pressure differential. Thus the same injector as used in reference 4 could not be used at flow rates below 0.345. The WDA-4.0 injector was ultimately chosen for this experiment, since it gave the desired range of liquid-air ratios corresponding to the fuel-air ratios in reference 4, which are listed in table I. Further discussion on evaluating fuel injectors appears in the appendix.

Figure 7 shows the effect of water pressure differential on water droplet D_{32} at a constant total-pressure drop of 3 percent across the swirler, with and without the venturi. While the use of the swirler changed the shape of the curve from the baseline in figure 6, the most striking

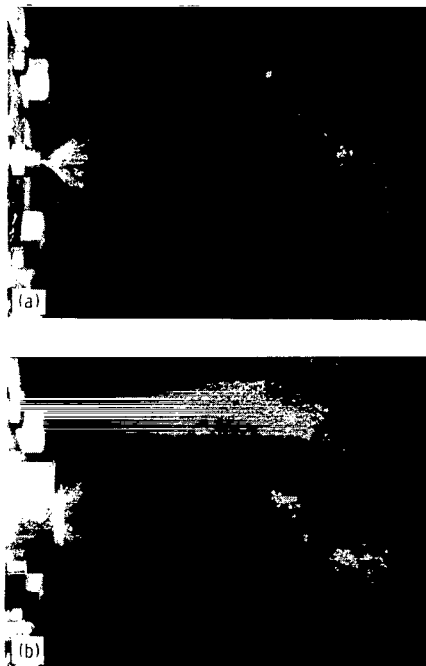
difference was how much the venturi had reduced D_{32} and improved atomization, as correctly assumed in reference 4. This improvement in atomization was attributed to the swirling air being confined in the venturi and thereby increasing air velocity at the venturi throat. Without the venturi, the swirling air quickly diverged and was less effective in atomizing the liquid. Figure 8 shows water sprays with and without the venturi. The spray in figure 8(b) has smaller and finer water droplets than that in figure 8(a).

The NO_x emission data in figure 9 (from ref. 4) show the effectiveness of the venturi in reducing the NO_x emission index. Thus, besides improving atomization of water sprays, the venturi also reduced NO_x emissions. Stated differently, the reduction in NO_x emissions with the use of a venturi in the combustion experiment of reference 4 can be attributed to reduced D_{32} . In reference 12, an empirical relation for drop size D_{32} takes the form

$$D_{32} = \frac{6 \times 10^4 \sigma^{0.6} \nu^{0.2} \dot{m}^{0.25}}{\Delta P^{0.4}} \quad (2)$$

where

D_{32} Sauter mean diameter, μm
 σ surface tension, N/m
 ν kinematic viscosity, m^2/sec
 \dot{m} mass flow rate, kg/sec
 ΔP injector pressure differential, Pa



(a) Without venturi.
 (b) With venturi.

Figure 8. - Water sprays from swirler and injector. Airflow pressure drop, 3 percent; water differential pressure, 0.690 megapascal.

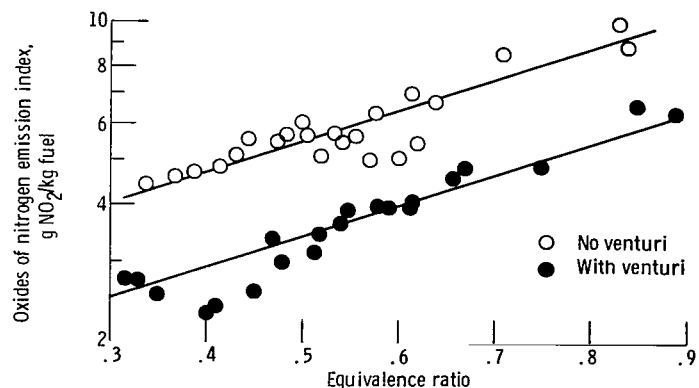


Figure 9. - Comparison of NO_x emissions from injector WDA-18, 0 with and without venturi (from ref. 4).

Since water was used in this experiment to simulate combustor tests using fuel, the following relation was used to calculate values of $D_{32,f}$ for the fuel sprays from measured values of $D_{32,w}$ determined from the water sprays:

$$D_{32,f} = D_{32,w} \frac{\left(\frac{v_w^{0.2} \sigma_w^{0.6} \dot{m}_w^{0.25}}{\Delta P_w^{0.4}} \right)_f}{\left(\frac{v_w^{0.2} \sigma_w^{0.6} \dot{m}_w^{0.25}}{\Delta P_w^{0.4}} \right)_w} \quad (3)$$

where

$$v_w = 1.39 \times 10^{-6} \text{ m}^2/\text{sec}$$

$$\sigma_w = 7.25 \times 10^{-2} \text{ N/m}$$

$$v_f = 1.35 \times 10^{-6} \text{ m}^2/\text{sec}$$

$$\sigma_f = 2.20 \times 10^{-2} \text{ N/m}$$

or

$$D_{32,f} = D_{32,w} \left(\frac{v_f}{v_w} \right)^{0.2} \left(\frac{\sigma_f}{\sigma_w} \right)^{0.6} \left(\frac{\dot{m}_f}{\dot{m}_w} \right)^{0.25} \left(\frac{\Delta P_w}{\Delta P_f} \right)^{0.4} \quad (4)$$

The subscripts f and w refer to fuel and water, respectively. The fuel and the water are both assumed to be at a temperature of 285 K. Equation (3) takes into account the differences in properties of fuel and water as well as the flow number of the injector (defined as liquid mass flow rate divided by the square root of the liquid pressure differential $\dot{m}/\sqrt{\Delta P}$). Equation (4) is a simplified form of equation (3). These normalized ratios, in equation (4), multiplied by the experimentally determined values of $D_{32,w}$ were used to calculate $D_{32,f}$ for the combustor test. It may be noted that evaporation and confinement of burning in the combustor are factors that were not included in the calculation of $D_{32,f}$. Calculations using these normalized ratios were made at the same pressure differential across the respective injectors so that $\Delta P_f = \Delta P_w$. This approach was used so that the liquid-air ratios and fluid injection velocities were increased at the same rate. The test conditions for both the combustion and ambient-pressure water tests are shown in table I. Table II shows the results of correlating computed $D_{32,f}$ with experimental values of NO_xEI (from ref. 4) obtained with and without the venturi. Differential pressure and equivalence ratio are also shown.

Figure 10 combines the NO_x emission index data from figure 9 and computed values of $D_{32,f}$ with and without the venturi from table II. This figure confirms again the theoretical effectiveness of the venturi mounted on the injector-swirler pair. The data were recorded at a swirler total-pressure drop of 3 percent. On the average, the venturi reduced droplet $D_{32,f}$ by 30 percent for operation at the same fuel flow rate.

TABLE II. - COMPARISON OF PREDICTED SAUTER MEAN DIAMETER AND EXPERIMENTAL NITROGEN
OXIDE EMISSIONS WITH AND WITHOUT A VENTURI NOZZLE

Pressure differ- ential, ΔP , MPa	Equivalence ratio, ϕ_f	No venturi			With venturi		
		Sauter mean diameter, $D_{32,f}$, μm	Nitrogen oxide emission index, NO_xEI , g NO_2/kg fuel (a)	$NO_xEI/(D_{32,f})^2$, (g NO_2/kg fuel)/ μm^2	Sauter mean diameter, $D_{32,f}$, μm	Nitrogen oxide emission index, NO_xEI , g NO_2/kg fuel (a)	$NO_xEI/(D_{32,f})^2$, (g NO_2/kg fuel)/ μm^2
0.386	0.528	100.6	5.80	5.73×10^{-4}	79.0	3.40	5.45×10^{-4}
.579	.646	94.4	6.90	7.74	68.0	4.05	8.76
.772	.749	83.2	8.15	11.77	56.4	4.75	14.95
.962	.837	70.5	9.20	18.49	50.2	5.40	21.42
1.158	.910	66.1	10.05	23.00	46.1	6.10	28.67

^aFrom ref. 4.

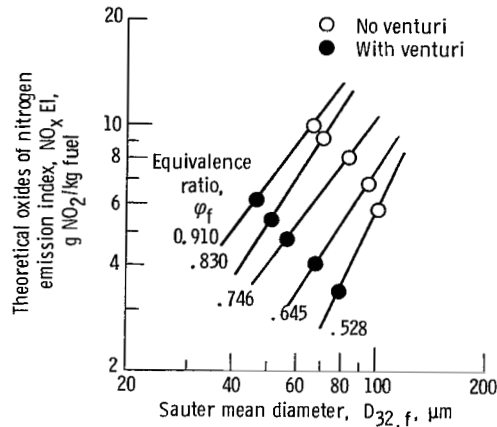


Figure 10. - Comparison of theoretical fuel droplet Sauter mean diameter and theoretical NO_x emissions with and without venturi at total-pressure drop across swirler of 3 percent.

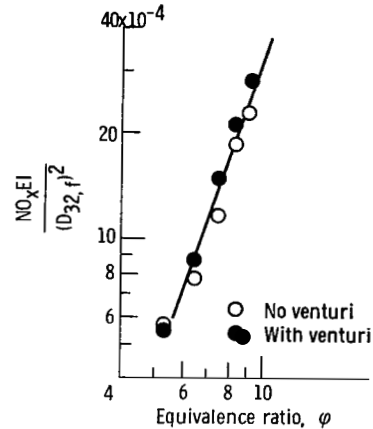


Figure 11. - Comparison of spray mixing with and without venturi when atomization is normalized.

Figure 11 shows $\text{NO}_x \text{EI} / (D_{32,f})^2$ plotted as a function of equivalence ratio ϕ . The term $\text{NO}_x \text{EI} / (D_{32,f})^2$ was used in the work of reference 7 to normalize $\text{NO}_x \text{EI}$ data based on $(D_{32,f})^2$ among the five combustor modules. The $\text{NO}_x \text{EI} / (D_{32,f})^2$ term was used here to determine if the venturi improved mixing as well as atomization. The data from table II plotted in figure 11 fall on one line. If the venturi had appreciably enhanced fuel-air mixing, two separate $\text{NO}_x \text{EI} / (D_{32,f})^2$ data lines, with and without the venturi, would be distinguishable. Therefore the main effect of the venturi was to increase the swirling air velocity and cause a decrease in D_{32} . Though data scatter is minimal in figure 11, a question remains as to what mechanism would produce mixing for this configuration. This indicates the need to further investigate atomization and mixing in combustors at various inlet air pressures and temperatures.

SUMMARY OF RESULTS

An experiment was conducted to determine the effect of a venturi nozzle on the Sauter mean diameter D_{32} of a spray produced by a simplex pressure-atomizing injector in a swirling airflow. Values of D_{32} for water sprays with and without a venturi nozzle were correlated with the oxides of nitrogen emission index $\text{NO}_x \text{EI}$ and equivalence ratio data reported in a previous combustor experiment. Use of a venturi with the simplex injector and air swirler decreased D_{32} by approximately 30 percent at a total air swirler pressure drop of 3 percent and a liquid-air ratio range of 0.528 to 0.910. This improvement in atomization was attributed to the swirling air being confined in the venturi and increasing air velocity in the venturi throat.

The $\text{NO}_x \text{EI} / (D_{32,f})^2$ term which normalized the $\text{NO}_x \text{EI}$ data with calculated values of $(D_{32,f})^2$ varied directly with equivalence ratio and correlated the data with and without the venturi. It can, therefore, be inferred that the venturi acted primarily to improve atomization by increasing relative air velocity and thus decreasing D_{32} and that the venturi did not contribute to fuel-air mixing. Thus, using a venturi with a

pressure-atomizing injector-swirler pair enhanced spray vaporization and decreased NO_x EI.

Lewis Research Center,
National Aeronautics and Space Administration,
Cleveland, Ohio, January 15, 1982.

APPENDIX - EVALUATION OF WDA-18.0 AND WDA-4.0

FUEL INJECTOR CHARACTERISTICS

Droplet Size and Distribution

An example of the output from the Malvern Particle and Droplet Size Distribution Analyzer is shown in figure 12. The first line of output is the peak PE, width W, and error E of the distribution. The first two coefficients are discussed later. The error E is a relative error number describing the accuracy of curve fit between the calculated Rosin-Rammler and actually measured droplet distributions. The first column gives mathematically determined divisions or "bins" of droplet size ranges in micrometers. The next three columns are the spray distributions as percent weight fraction, cumulative percent by weight, and normalized percent by number density. The last two columns are the calculated and actually measured energy distributions. The D_{32} can easily be calculated from PE and W. The simplified Rosin-Rammler expression is

$$D_{32} = \frac{PE}{\Gamma(1 - \frac{1}{W})}$$

where Γ is the tabulated gamma function.

Mass Flow Rate as Function of Pressure Differential

One preliminary method to describe fuel injectors was to plot the liquid flow rate against the liquid pressure differential, as shown in figure 13. This plot shows the effect of water and Jet A with WDA-18.0. Also plotted are data for WDA-4.0 showing its characteristics compared with WDA-18.0. Flow number can be simply calculated from this plot. Therefore an adequate basic description of the fuel injectors is provided by figures 6 and 13.

> PE= +82.0 W= +2.5 E= 00033222

D= +562.86	> +261.71	P= +0.00Z	R= +100.00Z	N= +0.00Z	C= 0438	A= 0388
D= +261.71	> +160.29	P= +0.48Z	R= +99.52Z	N= +0.00Z	C= 0665	A= 0713
D= +160.29	> +112.86	P= +10.36Z	R= +89.16Z	N= +0.17Z	C= 0982	A= 1070
D= +112.86	> +84.29	P= +23.42Z	R= +65.74Z	N= +1.04Z	C= 1328	A= 1385
D= +84.29	> +64.57	P= +23.42Z	R= +42.32Z	N= +2.41Z	C= 1694	A= 1627
D= +64.57	> +50.29	P= +16.81Z	R= +25.51Z	N= +3.77Z	C= 1951	A= 1931
D= +50.29	> +38.86	P= +11.19Z	R= +14.32Z	N= +5.37Z	C= 2044	A= 2047
D= +38.86	> +30.29	P= +6.37Z	R= +7.96Z	N= +6.55Z	C= 1901	A= 2015
D= +30.29	> +23.71	P= +3.56Z	R= +4.40Z	N= +7.68Z	C= 1663	A= 1805
D= +23.71	> +18.57	P= +1.99Z	R= +2.41Z	N= +8.93Z	C= 1405	A= 1448
D= +18.57	> +14.57	P= +1.09Z	R= +1.32Z	N= +10.17Z	C= 1153	A= 1123
D= +14.57	> +11.43	P= +0.60Z	R= +0.72Z	N= +11.60Z	C= 0938	A= 0892
D= +11.43	> +9.14	P= +0.31Z	R= +0.41Z	N= +12.04Z	C= 0749	A= 0682
D= +9.14	> +7.14	P= +0.19Z	R= +0.22Z	N= +14.99Z	C= 0589	A= 0535
D= +7.14	> +5.71	P= +0.10Z	R= +0.13Z	N= +15.28Z	C= 0458	A= 0440

Figure 12. - Example of output from Malvern particle and droplet size distribution analyzer.

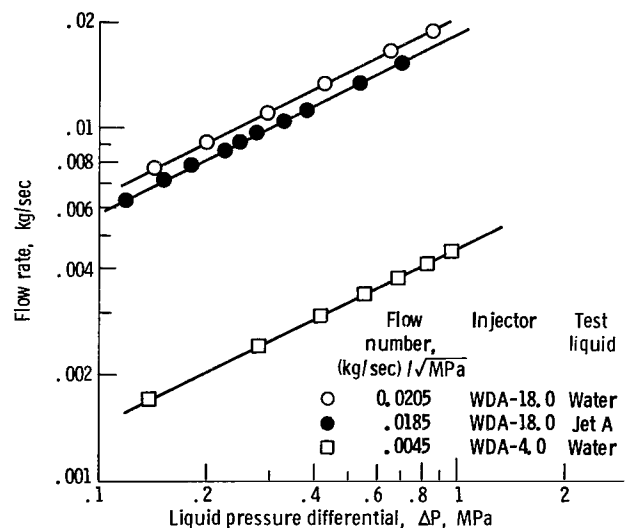


Figure 13. - Calibration curves for injectors WDA-18.0 and WDA-4.0 in still air.

Droplet Number Density

Figure 14 compares WDA-18.0 and WDA-4.0 in terms of droplet number density. These injectors had comparable droplet number densities in the range of interest, 39 to 160 micrometers.

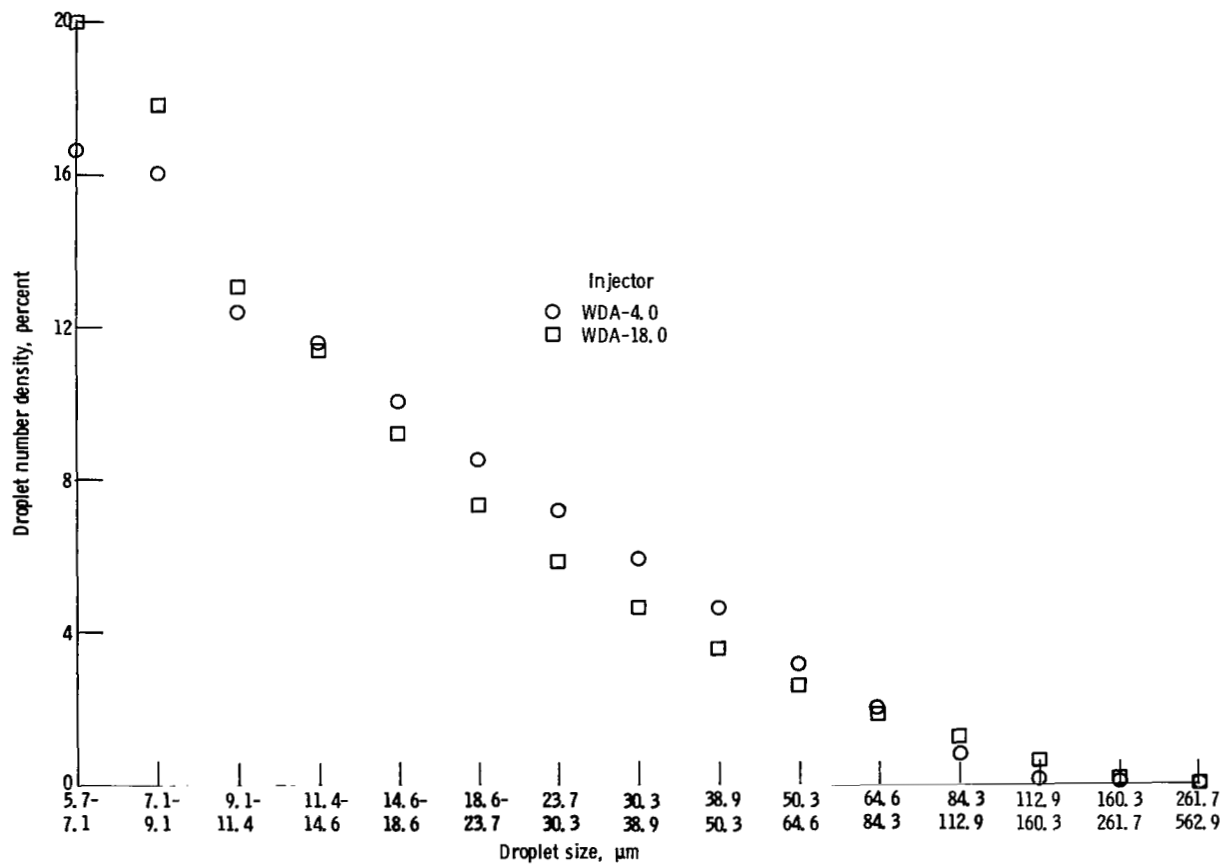


Figure 14. - Comparison of droplet number density for injectors WDA-18.0 and WDA-4.0. Water pressure differential, 0.690 megapascal.

REFERENCES

1. Heywood, John B.; Fay, James A.; and Chigier, Norman A.: Air Pollution from Aircraft. NASA CR-159712, 1979.
2. Jones, R. E.; et al.: Results and Status of the NASA Aircraft Engine Emission Reduction Technology Programs. NASA TM-79009, 1978.
3. Szaniszlo, Andrew, J.: The Advanced Low-Emissions Catalytic-Combustor Program. Phase I - Description and Status, NASA TM-79049, 1979.
4. Ercegovic, David B.: Effect of Swirler-Mounted Mixing Venturi on Emissions of Flame-Tube Combustor Using Jet A Fuel. AVRADCOM TR 78-41, NASA TP-1393, 1979.
5. Buchele, Donald R.: Scanning Radiometer for Measurement of Forward-Scattered Light to Determine Mean Diameter of Spray Particles. NASA TM X-3454, 1976.
6. Ingebo, Robert D.: Atomization of Water Jets and Sheets in Axial and Swirling Airflows. NASA TM-79043, 1979.
7. Ingebo, Robert D.: Atomizing Characteristics of Swirl Can Combustor Modules With Swirl Blast Fuel Injectors. NASA TM-79297, 1980.
8. Rosin, P.; and Rammler, E.: Laws Governing the Fineness of Powdered Coal. J. Inst. Fuel, vol. 7, no. 31, Oct. 1933, pp. 29-36.
9. Weiner, Bruce B.: Particle and Spray Sizing Using Laser Diffraction. Optics in Quality Assurance II, Harvey L. Kasdan, ed., Proceedings of the Society of Photo-Optical Instrumentation Engineers, vol. 170, SPIE, 1979, pp. 53-62.
10. Swithenbank, J.; et al.: A Laser Diagnostic Technique for the Measurement of Droplet and Particle Size Distribution. AIAA Paper 76-69, Jan. 1976.
11. Simmons, H. C.; Harding, C. F.: Some Effects of Using Water as a Test Fluid in Fuel Nozzle Spray Analysis. ASME Paper 80-GT-90, March 1980.
12. The Design and Development of Gas Turbine Combustors. Volume 1: Component Theory and Practice. NREC Report No. 1344-1, Northern Research and Engineering Corp., 1980, pp. 6.16-6.26.

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16. Abstract <p>An experiment was conducted to determine the effect of a venturi nozzle on the Sauter mean diameter D_{32} of a water spray produced by a simplex pressure-atomizing injector in a swirling airflow. A Malvern Particle and Droplet Size Distribution Analyzer, Type S. T. 1800, was used to measure D_{32} of the water sprays. The water spray was studied at ambient temperature (293 K) and atmospheric pressure. The venturi reduced D_{32} by an average of 30 percent when installed with a simplex injector and air swirler. The venturi primarily improved atomization of the injector spray by increasing relative air velocity. The small drop size enhanced vaporization and therefore would decrease oxides of nitrogen (NO_x) in a combustor. The decrease in drop size provided by the addition of a venturi explains the results obtained in a previous small-scale research combustor wherein NO_x emission indices decreased as a result of this hardware modification.</p>				13. Type of Report and Period Covered Technical Paper	
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